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<b>(54) Title:</b> INTERNAL COMBUSTION ENGINE WITH COMBINED CAM AND ELECTRO-HYDRAULIC ENGINE VALVE CONTROL    <b>(57) Abstract</b> <p>An internal combustion engine (10) has electrically controlled hydraulic linkages between engine cams (40) and engine cylinder valves (30). If it is desired to skip a cam lobe or to modify the response of an engine cylinder valve (30) to a cam lobe (42), hydraulic fluid is selectively released from the associated hydraulic linkage to permit lost motion between the cam (40) and the engine cylinder valve (30). Electrically controlled hydraulic fluid valves are used to produce the selective release of hydraulic fluid from the hydraulic linkages. The mode of operation of the engine can be changed (e.g., from positive power mode to compression release engine braking mode or vice versa), or more subtle changes can be made to modify the timing and/or extent of engine cylinder valve (30) openings to optimize engine performance for various engine or vehicle operating conditions (e.g., different engine or vehicle speeds). The valves (30) can be controlled to produce an exhaust gas recirculation event during various operating modes of the engine.</p>		

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## **INTERNAL COMBUSTION ENGINE WITH COMBINED CAM AND ELECTRO-HYDRAULIC ENGINE VALVE CONTROL**

### **CROSS REFERENCE TO RELATED APPLICATIONS**

This application is a continuation-in-part of U.S. Patent Application No. 08/955,509, filed October 22, 1997, U.S. Patent No. 5,839,453, which is a continuation of U.S. Patent Application No. 08/772,781, filed December 24, 1996, U.S. Patent No. 5,680,841, which is a continuation of U.S.  
5 Patent Application No. 08/512,528, filed August 8, 1995.

### **FIELD OF THE INVENTION**

This invention relates to internal combustion engines, and more particularly to internal combustion engines with valves that are opened by cams cooperating with hydraulic circuits to produce at least one of a main exhaust event, an engine regarding event and an exhaust gas  
10 recirculation event. The valves are partly controlled by electrically operated hydraulic fluid valves to modify the timing and duration of the events.

### **BACKGROUND OF THE INVENTION**

In most internal combustion engines the engine cylinder intake and exhaust valves are opened and closed (at least for the most part) by cams in the engine. This makes it relatively difficult and  
15 perhaps impossible to adjust the timings and/or amounts of engine valve openings to optimize those openings for various engine operating conditions such as changes in engine speed.

It is known to include hydraulic lash adjusting mechanisms in the linkage between an engine cam and the engine cylinder valve controlled by that cam to make it possible to make relatively small adjustments in the valve strokes relative to the profile of the cam (see, for example, Rembold,  
20 et al., U.S. Patent 5,113,812 and Schmidt et al., U.S. Patent 5,325,825). These lash adjustments may be used to provide additional valve openings when it is desired to convert the engine from positive power mode to compression release engine braking mode (see, for example, Cartledge, U.S. Patent 3,809,033 and Gobert et al., U.S. Patent 5,145,890). Hydraulic circuitry may also be used to cause  
25 a part of the engine other than the cam which normally controls an engine valve to provide additional openings of the valve when it is desired to convert the engine from positive power mode to compression release engine braking mode (see, for example, Cummins, U.S. Patent 3,220,392, and Hu, U.S. Patent 5,379,737).

Schechter, U.S. Patent 5,255,641, shows in Fig. 16 that an engine cam can be linked to an engine cylinder valve by a hydraulic circuit which includes a solenoid valve for selectively releasing hydraulic fluid from the hydraulic circuit. Schechter points out that various phases of the engine cylinder valve lift versus the cam curve can be obtained by varying the solenoid voltage pulse timing and duration. However, Schechter does not suggest that any lobe on the cam can be completely overridden in this way. It may not be possible to convert an engine from positive power mode to compression release engine braking mode and vice versa without the ability to selectively completely override any lobe on an engine cam.

Sickler, U.S. Patent 4,572,114, shows internal combustion engine cylinder valve control which essentially uses two substantially separate hydraulic circuits for controlling the motion of each engine cylinder valve. One of these two hydraulic circuits controls selective decoupling of each engine cylinder valve from its normal cam-driven mechanical input. The other hydraulic circuit provides alternative hydraulic inputs to the engine cylinder valve when the normal mechanical input is decoupled. The control for these two hydraulic systems may be essentially mechanical and/or hydraulic as in Fig. 5, or it may be essentially electronic as shown in Fig. 7. The two hydraulic circuits may have a common source of hydraulic fluid and they may have other cross-connections, but they are largely separate in operation and they each require a separate hydraulic connection (e.g., 136 and 212 in Fig. 5 or 258 and 212 in Fig. 7) to each cylinder valve operating mechanism.

From the foregoing it will be seen that the known hydraulic modifications of cam control for engine cylinder valves tend to be either relatively limited in extent and purpose (e.g., as in Fig. 16 of the Schechter patent) or to require relatively complex hydraulic circuitry (e.g., as in the Sickler patent).

### OBJECTS OF THE INVENTION

It is therefore an object of this invention to provide improved and simplified hydraulic circuitry which can be used to more extensively modify the operation of engine cylinder valves in response to engine cams.

It is another object of this invention to provide relatively simple hydraulic circuitry which can be used selectively to partly or completely suppress any engine valve operation associated with the engine cam that otherwise controls that engine valve, for example, switch the engine between positive power mode operation, compression release engine braking mode operation and exhaust gas

recirculation mode operation and/or to adjust the timing of engine valve openings for various engine operating conditions.

### SUMMARY OF THE INVENTION

These and other objects of the invention are accomplished in accordance with the principles of the invention by providing a hydraulic circuit linkage in the connection between an engine cam and an engine valve associated with that cam. The hydraulic circuit is partly controlled by an electrically operated hydraulic valve (e.g., for selectively relieving hydraulic fluid pressure in the hydraulic circuit). The hydraulic circuit is preferably constructed so that when the electrically operated hydraulic valve relieves hydraulic fluid pressure in that circuit, there is sufficient lost motion between the mechanical input to the circuit and the mechanical output from the circuit to prevent any selected cam function or functions including but not limited to engine braking, compression release retarding, and exhaust gas recirculation from being transmitted to the engine valve associated with that cam. This allows the electrically controlled hydraulic circuit to fully control which cam function(s) the associated engine valve will respond to and which cam function(s) the engine valve will not respond to. In addition, the electrically operated hydraulic circuit can modify the response of the engine valve to various cam functions (e.g., to modify the timing of engine valve responses to those cam functions). In the preferred embodiments only a single hydraulic fluid connection is needed to the mechanism of each valve. Also in the preferred embodiments the ultimate input for all openings of each engine valve comes from a single cam that is associated with that valve.

Further features of the invention, its nature and various advantages will be more apparent from the accompanying drawings and the following detailed description of the preferred embodiments.

### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in connection with the following figures in which like reference numbers refer to like elements and wherein:

Fig. 1 is a schematic diagram of an internal combustion engine according to an embodiment of the present invention;

Fig. 2a is a simplified diagram of an illustrative signal waveform usable in the apparatus of Fig. 1 or in any of the additional embodiments shown in Figs. 8-10;

Fig. 2b is a simplified diagram of illustrative motion of an engine cylinder valve in the apparatus of Fig. 1 or in any of the additional embodiments shown in Figs. 8-10;

Figs. 2c, 2e, 3a, 4a, 5a, 6a, 7a, 7c, 7e, and 7g are diagrams of the same general kind as Fig. 2a;

5 Figs. 2d, 2f, 3b, 4b, 5b, 6b, 7b, 7d, 7f, and 7h are diagrams of the same general kind as Fig. 2b;

Fig. 8 is a diagram similar to Fig. 1 showing another embodiment of the invention;

Fig. 9 is another diagram similar to Fig. 1 showing another embodiment of the invention; and

Fig. 10 is yet another diagram similar to Fig. 1 showing yet another embodiment of the  
10 invention.

### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An embodiment of an internal combustion engine 10 constructed in accordance with the present invention is illustrated in Fig. 1. The engine 10 includes an engine cylinder head 20 in which at least one engine cylinder valve 30 is movably mounted. The at least one engine cylinder valve  
15 30 control the flow of gas to and from the cylinders (not shown) of the engine 10. Valve 30, as shown, is an exhaust valve, but it will be understood that valve 30 can alternatively be an intake valve. The at least one valve 30 is resiliently urged toward its upper (closed) position by prestressed compression coil springs 32.

The opening of valve 30 can be produced by lobes such as 42a, 42b and 42c on rotating  
20 engine cam 40. Cam 40 may conventionally rotate once for every two revolutions of the engine crankshaft (assuming that the engine is a four-cycle engine). Cam 40 may be synchronized with the engine crankshaft so that cam lobe 42a passes master piston 60 (described below) during the exhaust stroke of the engine piston associated with valve 30. Cam lobe 42a is therefore the lobe for producing normal exhaust stroke openings of exhaust valve 30 during positive power mode  
25 operation of the engine. Cam lobe 42b passes master piston 60 near the end of the compression stroke of the engine piston associated with valve 30. Cam lobe 42b can therefore be used to produce compression release openings of exhaust valve 30 during compression release engine braking operation of the engine. A third cam lobe 42c is provided to open the exhaust valve 30 at predetermined intervals to produce, for example, to modify the compression release opening of the  
30 exhaust valve, as described below or to produce an exhaust gas recirculation event, as discussed below. If valve 30 is an intake valve rather than an exhaust valve, then the lobes 42 on the

associated cam 40 will have shapes and angular locations different from those shown in Fig. 1, but the underlying operating principles are the same.

Cam 40 is selectively linked to valve 30 by a hydraulic circuit 50 which will now be described. In Fig. 1, a housing 52 in which hydraulic circuit 50 is disposed is fixed and stationary relative to engine cylinder head 20. Hydraulic circuit 50 includes a master piston 60 which is hydraulically coupled to a slave piston 70. Master piston 60 receives a mechanical input from lobes 42a, 42b and 42c on cam 40, and if the hydraulic subcircuit 64 between the master and slave pistons is sufficiently pressurized, that input is hydraulically transmitted to slave piston 70 to cause the slave piston to produce a corresponding mechanical output to open valve 30.

When the engine is operating, a hydraulic fluid pump 80 supplies pressurized hydraulic fluid from sump 78 to subcircuit 64 via check valves 82 and 84. The hydraulic fluid pressure supplied by pump 80 is sufficient to push master piston 60 out into contact with the peripheral surface of cam 40 and to push slave piston 70 into contact with the upper end of the stem of valve 30, but it is not sufficient to cause slave piston 70 to open valve 30. For example, the hydraulic fluid pressure supplied by pump 80 may be approximately 50 to 100 psi. Any over-pressure produced by pump 80 is relieved by relief valve 86, which returns hydraulic fluid to the inlet of pump 80. The hydraulic fluid may be engine lubricating oil, engine fuel, or any other suitable fluid.

Hydraulic fluid accumulator 90 helps keep subcircuit 64 filled with hydraulic fluid of at least approximately the output pressure produced by pump 80. An electrically controlled hydraulic valve 100 is provided for selectively relieving hydraulic fluid pressure (above the output pressure of pump 80) from subcircuit 64. When valve 100 is closed, hydraulic fluid is trapped in subcircuit 64. Subcircuit 64 will then hydraulically transmit a mechanical input from cam 40 and master piston 60 to slave piston 70, thereby causing the slave piston to produce a mechanical output which opens valve 30. On the other hand, when valve 100 is open, hydraulic fluid can escape from subcircuit 64 to accumulator 90. This prevents subcircuit 64 from transmitting an input from cam 40 and master piston 60 to slave piston 70. Valve 30 therefore does not open in response to the cam input. As such, the motion produced by lobes 42b and 42c, for example, can be absorbed so that engine braking or exhaust gas recirculation events are not produced. Preferably valve 100 can vent from subcircuit 64 all the hydraulic fluid flow produced by the longest stroke of master piston 60 that results from any lobe 42 on cam 40. In this way valve 100 can be used to effectively completely cancel or suppress (by means of lost motion in subcircuit 64) any input from cam 40. If accumulator

90 receives too much hydraulic fluid, its plunger moves far enough to the left to momentarily open a drain 92 back to hydraulic fluid sump 78, as shown in Fig. 1.

Valve 100 is controlled by electronic control circuitry 110 associated with engine 10. Control circuit 110 receives various inputs 112 from engine and vehicle instrumentation 114 (which may include inputs initiated by the driver of the vehicle) and produces output signals 108 for appropriately controlling valve 100 (and other similar valves in engine 10). For example, control circuit 110 may control valve 100 differently depending on such factors as the speed of the engine or vehicle, whether the engine is in positive power mode or compression release engine braking mode, etc. The control circuit 110 may include a programmed microprocessor for performing algorithms or look-up table operations to determine output signals 108 appropriate to the inputs 112 that the control circuit is currently receiving. Instrumentation 114 includes engine sensors (e.g., an engine crankangle position sensor) for maintaining basic synchronization between the engine and control circuit 110.

Figs. 2a through 2f show illustrative control signals for valves like valve 100 and resulting motions of engine valves like valve 30 under various engine operating conditions. For example, Fig. 2a shows the signal 108 from control circuit 110 for controlling the valve 100 associated with the exhaust valve(s) 30 of a typical engine cylinder during positive power mode operation of the engine. In connection with Fig. 2a, the valve 100 is closed when the signal trace is high. The numbers along the base line in Fig. 2a are engine crankangle degrees and apply to Figs. 2b through 2p. Fig. 2c shows the corresponding signal 108 during compression release engine braking operation of the engine. Fig. 2e shows the signal 108 from control circuit 110 for controlling the valve 100 associated with the intake valve(s) 30 of the same engine cylinder with which Figs. 2a and 2c are associated. In this example, Fig. 2e is the same for both positive power and compression release engine braking mode operation of the engine.

As shown in Figs. 2a and 2b, because the valve 100 associated with the hydraulic subcircuit 64 for the exhaust valve is closed when the exhaust lobe 42a on cam 40 passes master piston 60, that lobe cause exhaust valve 30 to open as shown in fig. 2b during the exhaust stroke of the associated engine cylinder (i.e., between engine crankangles 180° and 360°). This is the motion of exhaust valve 30 that is appropriate for positive power mode operation of the engine. Fig. 2a shows that valve 100 is open when compression release lobe 42b on cam 40 passes master piston 60 (near engine crankangle 0° or 720°). Exhaust valve 30 therefore does not open in response to lobe 42b.



On the other hand, Figs. 2c and 2d show valve 100 being closed near top dead center of each compression stroke of the engine cylinder (engine crankangle 0° or 720°) but open during the exhaust stroke of that cylinder. This causes exhaust valve 30 to open as shown in Fig. 2d in response to compression release lobe 42b passing master piston 60, but it allows exhaust valve 30 to remain closed as exhaust lobe 42a passes master piston 60. Figs. 2e and 2f show that the valve 100 associated with the intake valve of the engine cylinder is closed during the intake stroke of the engine cylinder (between engine crankangles 360° and 540°). This causes the intake valve 30 of that cylinder to open as shown in Fig. 2f in response to an intake lobe on an intake valve control cam 40 associated with that engine cylinder. In this embodiment the operation of the intake valve remains the same for positive power mode and compression release engine braking mode operation of the engine.

Additionally or alternatively to allowing selection of which cam lobes 42 the engine valves 30 will respond to, the apparatus of this invention allows the response of the engine valves 30 to any cam lobe to be varied if desired. For example, Figs. 3a and 3b are respectively similar to Figs. 2a and 2b, but show that if control circuit 110 delays the closing of valve 100 somewhat (as compared to Fig. 2a), valve 30 begins to open somewhat later. In other words, the first part of exhaust lobe 42a is suppressed or ignored. In addition, because some hydraulic fluid is allowed to escape from subcircuit 64 during the initial part of exhaust lobe 42a, valve 30 does not open as far in Fig. 3b as it does in Fig. 2b, and valve 30 closes sooner in Fig. 3b than in Fig. 2b. The principles illustrated by Figs. 3a and 3b are equally applicable to any of the other types of valve motion shown in the Fig. 2 group.

Figs. 4a and 4b show another example of using valve 100 to modify the response of engine valve 30 to cam lobe 42a. Again, Figs. 4a and 4b are respectively similar to Figs. 2a and 2b, but show control circuit 110 re-opening valve 100 sooner than is shown in Figs. 2a. As shown in Fig. 4b this causes engine valve 30 to re-close sooner than in Fig. 2b. Re-opening valve 100 before the final portion of cam lobe 42a has passed master piston 60 causes valve 30 to ignore that final portion of the cam lobe, thereby allowing valve 30 to re-close sooner than it would under full control of the cam. Again, the principles illustrated by Figs. 4a and 4b are equally applicable to any of the other types of valve motion shown in the Fig. 2 or Fig. 3 groups.

Figs. 5a and 5b show yet another example of using valve 100 to modify the response of engine valve 30 to cam lobe 42a. Again Figs. 5a and 5b are respectively similar to Figs. 2a and 2b.

Fig. 5a shows control circuit 110 opening the associated valve 100 briefly as exhaust lobe 42a approaches its peak. This allows some hydraulic fluid to escape from subcircuit 64, thereby preventing valve 30 from opening quite as far as in Fig. 2b. As another consequence, valve 30 re-closes somewhat earlier than in Fig. 2b.

5 Another example of modulation of valve 100 of the general type shown in Fig. 5a is illustrated by Figs. 6a and 6b. Once again, Figs. 6a and 6b are respectively similar to Figs. 2a and 2b, except that during the latter portion of exhaust lobe 42a control circuit 110 begins to rapidly open and close valve 100. This enables some hydraulic fluid to escape from subcircuit 64, which accelerates the closing of valve 30, although the valve 30 closing still remains partly under the  
10 control of exhaust lobe 42a. The principles illustrated by Figs. 5a through 6b are equally applicable to any of the other types of valve motion shown in the Fig. 2, Fig. 3, or Fig. 4 groups. Moreover, valve modulation of the type shown in Fig. 6a and with any desired duty cycle (ratio of valve open time to valve close time) can be used at any time during a cam lobe to provide any of a wide range of modifications of the response of the associated engine valve to the cam lobe.

15 Figs. 7a through 7h illustrate how the present invention can be used to cause engine 10 to operate in another way during compression release engine braking. Figs. 7a through 7d are respectively similar to Figs. 2a, 2b, 2e, and 2f and show the same positive powder mode operation of the engine as is shown in the Fig. 2 group. Fig. 7e shows control of the valve 100 associated with the exhaust valve(s) during compression release engine braking, and Fig. 7g shows control of the  
20 valve 100 associated with the intake valve(s) during compression release engine braking. Figs. 7f and 7h show exhaust and intake valve motion, respectively, during compression release engine braking. In order to produce additional exhaust valve openings 120 in Fig. 7f, an additional lobe 42c (Fig. 1) is provided on cam 40. As shown in Fig. 7e, during compression release engine braking the valve 100 associated with the exhaust valve(s) is opened throughout the normal exhaust stroke of  
25 the engine to suppress the normal exhaust valve opening. However, this valve 100 is closed near the end of the expansion stroke (near engine crankangle 540°) and again near the end of the compression stroke (near engine crankangle 0° or 720°). This causes exhaust valve 30 to open (as at 120) in response to cam lobe 40c near the end of the expansion stroke (to charge the engine cylinder with a reverse flow of gas from the exhaust manifold of the engine). Exhaust valve 30  
30 opens again in response to cam lobe 42b near the end of the compression stroke (to produce a compression release event for compression release engine braking). Figs. 7g and 7h show that the

associated intake valve 30 is not opened at all during this type of compression release engine braking operation.

The type of compression release engine braking operation shown in Figs. 7e through 7h may be especially advantageous when the engine is equipped with an exhaust brake for substantially closing the exhaust system of the engine when engine retarding is desired. This increases the pressure in the exhaust manifold of the engine, making it possible to supercharge the engine cylinder when exhaust valve opening 120 occurs. This supercharge increases the work the engine must do during the compression stroke, thereby increasing the compression release retarding the engine can produce.

10 Figs. 2a through 7h show that the present invention can be used to modify the responses of the engine valves to the engine cam lobes in many different ways. These include complete omission of certain cam lobes at certain times, or more subtle alteration of the timing or extent of engine valve motion in response to a cam lobe. These modifications may be made to change the mode of operation of the engine (e.g., from positive powder mode to compression release engine braking mode or vice versa) or to optimize the performance of the engine for various engine or vehicle operation conditions (e.g., changes in engine or vehicle speed) as sensed by engine or vehicle instrumentation 114.

The present invention may be used to produce an exhaust gas recirculation event. Exhaust gas recirculation may be accomplished using lobe 42c or other suitable lobes on cam 40. When exhaust gas recirculation is desired, the valve 100 is closed such that the subcircuit 64 is fully charged such that the motion of the master piston 60 is transferred to slave piston 70 to open valve 30 to effectuate exhaust gas recirculation. The valve 100 may be operated, as discussed above, to control the timing and duration of the exhaust gas recirculation event. For example, the valve 100 may be held open to delay the start of the exhaust gas recirculation event. Similarly, the valve 100 may be opened during the exhaust gas recirculation event to absorb some of the motion derived from the lobe 42c to shorten the exhaust gas recirculation event. It is contemplated by the present invention that the valve 100 can be operated to modify the exhaust gas recirculation event.

Fig. 8 shows another embodiment of the invention in which the electrically controlled hydraulic circuitry of this invention is partly built into the overhead rockers of engine 10a. (To the extent that components in Fig. 8 are related to components in Fig. 1, the same reference numbers are used again in Fig. 8, but with a suffix letter "a". Substantially new elements in Fig. 8 have

previously unused reference numbers, but again a suffix letter "a" is added for uniformity of references to Fig. 8.)

As shown in Fig. 8, representative rocker 130a is rotatably mounted on rocker shaft 140a. The right-hand portion of rocker 130a (as viewed in Fig. 8) carries a rotatable cam follower roller 132a which bears on the peripheral cam surface of rotating cam 40a. Hydraulic subcircuit 64a extends from a source of pressurized hydraulic fluid (which is mounted for reciprocation in the left-hand portion of rocker 130a). The ultimate source of the pressurized hydraulic fluid in shaft 140a may be a pump arrangement similar to elements 78, 80, and 86 in Fig. 1. Electrically controlled hydraulic valve 100a can selectively release hydraulic fluid from subcircuit 64a out over the top of rocker 130a. Valve 100a is controlled by control circuitry similar to element 110 in Fig. 1.

The apparatus of Fig. 8 can be made to operate in a manner similar to that described above for Fig. 1. The pressure of the hydraulic fluid supply is great enough to push slave piston 70a out into contact with the upper end of engine valve 30a. However, this pressure is not great enough to open valve 30a against the valve-closing force of springs 32a. If valve 100a is closed when a cam lobe 42aa or 42ba passes roller 132a, the hydraulic fluid trapped in subcircuit 64a causes slave piston 70a to open valve 30a. On the other hand, if valve 100a is open when a cam lobe 42aa or 42ab passes roller 132a, slave piston 70a will move into rocker 130a, thereby expelling some hydraulic fluid from subcircuit 64a and allowing valve 30a to remain closed despite the passage of a cam lobe 42. any of the techniques for modifying engine valve response to cam lobes that are illustrated by Figs. 2a through 7h are equally applicable to the embodiment shown in Fig. 8. thus it is again preferred that the lost motion available in hydraulic subcircuit 64a is sufficient to allow any lobe on cam 40a to be completely ignored. More subtle modifications of the timing and/or extent of engine valve response to cam lobes are also possible as is discussed above in connection with Figs. 2a through 7h.

Fig. 9 shows another embodiment of the present invention which includes an accumulator 90b and check valve 84b, respectively similar to accumulator 90 and check valve 84 in Fig. 1. Elements in Fig. 9 that are similar to elements in Fig. 8 have the same reference numbers, but with the suffix letter "b" rather than "a" as in Fig. 8. When valve 100b is open, it releases hydraulic fluid from subcircuit 64b to accumulator 90b in a manner similar to the embodiment shown in Fig. 1. In other respects the operation of the Fig. 9 embodiment is similar to operation of the embodiment shown in Fig. 8, and thus it will not be necessary to repeat the explanation of Fig. 8 for Fig. 9.

Fig. 10 shows yet another embodiment which is similar to the embodiment shown in Fig. 9 but with the addition of master piston **60c** (similar to master piston **60** in Fig.1) to hydraulic subcircuit **64c**. elements in Fig. 10 which are similar to elements in Fig. 9 have the same reference numbers, but with the suffix letter "c" rather than "b" as in Fig. 9. The operation of this embodiment  
5 is similar to that of the embodiment shown in Fig. 9, so it will not be necessary to repeat the explanation of the Fig. 9 for Fig. 10.

It will be understood that the foregoing is only illustrative of the principles of the invention, and that various modifications can be made by those skilled in the art without departing from the scope and spirit of the invention. For example, while Figs. 1 and 8-10 suggest that there is one exhaust or intake valve **30** per engine cylinder, it is quite common to provide two valves of each type in each cylinder. The apparatus of this invention can be readily modified to control multiple intake and/or exhaust valves per cylinder.

**What is Claimed Is:**

1. An internal combustion engine comprising:  
at least one engine cylinder valve which is selectively opened and closed;  
a cam having a plurality of lobes synchronized with possible openings of said at  
least one engine cylinder valve;  
5 a hydraulic linkage containing hydraulic fluid operatively coupled between said  
cam and said at least one engine cylinder valve for selectively responding to said lobes by  
causing said valve to open; and  
a hydraulic fluid control assembly for selectively controlling hydraulic fluid  
pressure in said hydraulic linkage to selectively modify the openings of said engine cylinder  
10 valve in response to said lobes, said hydraulic fluid control being selectively operable to allow  
said engine cylinder valve to remain completely closed in response to any first one of said lobes  
and to open in response to any second one of said lobes.
2. The apparatus defined in claim 1, wherein said hydraulic fluid control comprises a  
valve for selectively releasing hydraulic fluid from said hydraulic linkage.
3. The apparatus defined in claim 2, wherein said valve is an electrically operated  
valve controlled by electronic control circuitry.
4. The apparatus defined in claim 1, further comprising:  
a supply of hydraulic fluid at a first, relatively low, positive pressure; and  
a check valve for allowing said hydraulic fluid to flow from said supply into  
said hydraulic linkage but not in an opposite direction, said first pressure being  
5 insufficient to  
cause said hydraulic linkage to open said engine cylinder valve.
5. The apparatus defined in claim 4, wherein said supply comprises a hydraulic fluid  
accumulator for maintaining a quantity of hydraulic fluid at approximately said first pressure,  
and wherein said hydraulic fluid control comprises an electrically operated valve for selectively  
releasing hydraulic fluid from said hydraulic linkage to said accumulator.
6. The apparatus defined in claim 5, further comprising:  
electronic control circuitry for controlling said electrically operated valve.
7. The apparatus defined in claim 1, wherein said at least one engine cylinder valve  
is an exhaust valve, wherein said plurality lobes include an exhaust lobe, a compression release

lobe and an exhaust gas recirculation lobe, and wherein said hydraulic fluid control is responsive to an engine operating mode.

8. The apparatus defined in claim 7, wherein said hydraulic fluid control selectively delays an opening of said at least one engine cylinder valve in response to at least one of said plurality of lobes during predetermined engine operating conditions.

9. A system for an internal combustion engine capable of producing exhaust gas recirculation, said system comprising:

at least one engine cylinder exhaust valve which is selectively openable and closed;

5 a cam having an exhaust gas recirculation lobe synchronized with a possible compression release opening of said exhaust valve;

a hydraulic linkage containing hydraulic fluid operatively coupled between said cam and said exhaust valve for selectively responding to said lobe by causing said valve to open; and

10 a hydraulic fluid control responsive to a variable operating condition of said engine for selectively controlling hydraulic fluid pressure in said hydraulic linkage to selectively modify the openings of said exhaust valve in response to said lobe so that said openings are adapted to a current value of said variable operating condition.

10. The system according to claim 9, wherein said hydraulic fluid control controls said hydraulic fluid pressure in said hydraulic linkage by selectively releasing hydraulic fluid from said hydraulic fluid linkage.

11. The system according to claim 9, wherein said hydraulic fluid control selectively modifies commencement time of said openings relative to commencement time of said lobe.

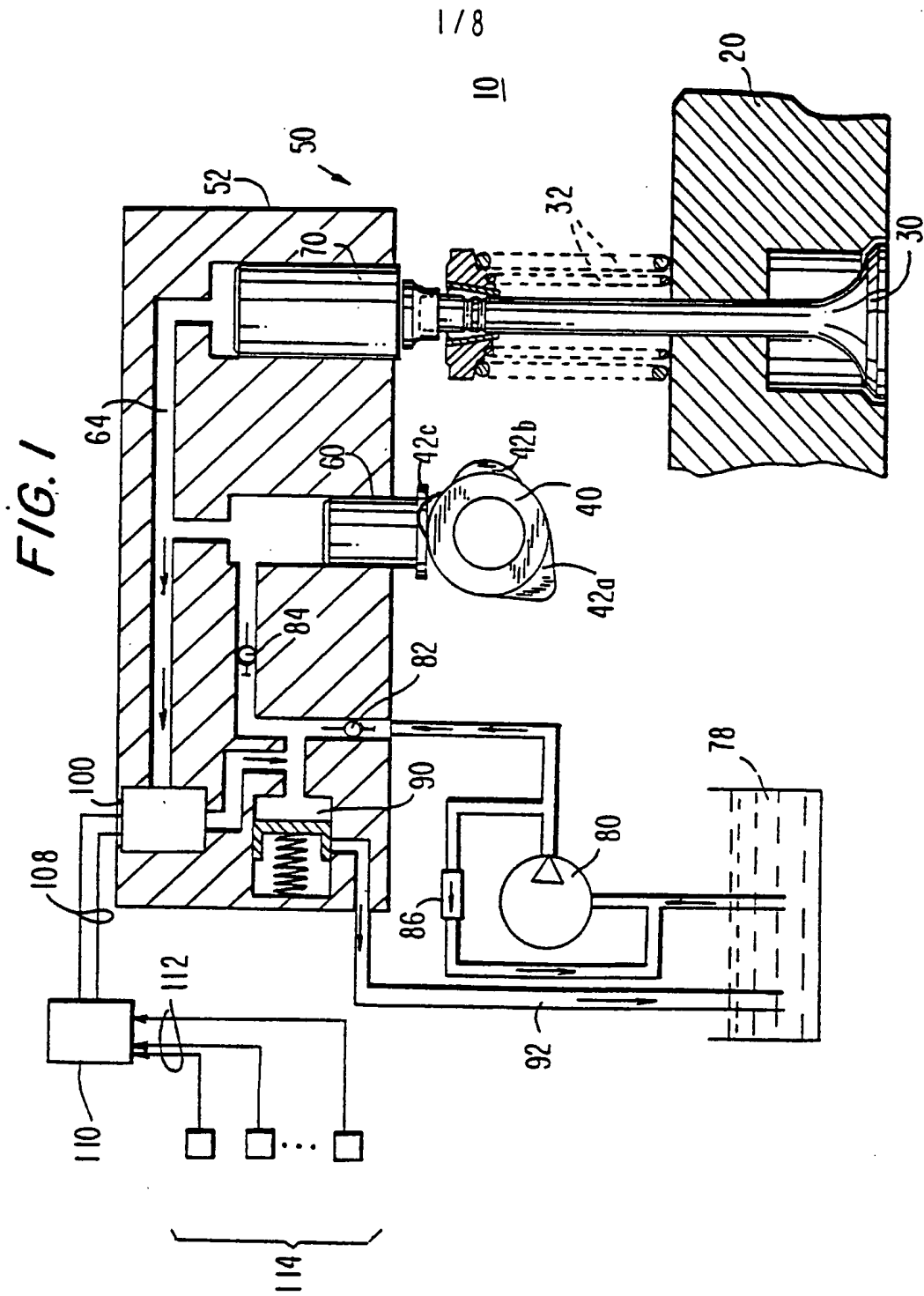
12. The system according to claim 9, wherein said hydraulic fluid control selectively modifies end termination time of said openings relative to end termination time of said lobe.

13. The system according to claim 9, wherein said hydraulic fluid control selectively modifies opening distance of said openings relative to profile prominence of said lobe.

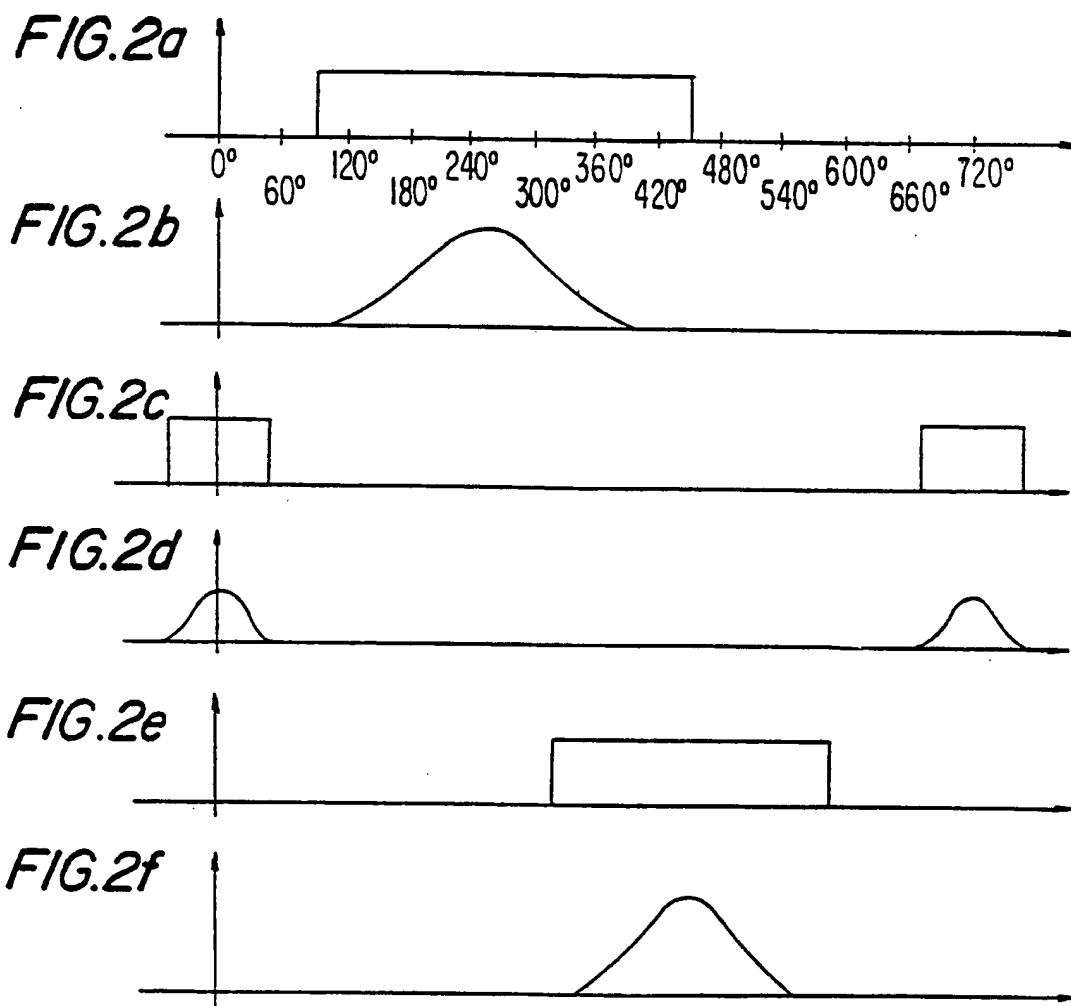
14. The system according to claim 9, wherein said exhaust valve reciprocates relative to a cylinder head of said engine, and wherein said hydraulic linkage is disposed in a structure which is fixed and stationary relative to said cylinder head.

15. The system according to claim 9, wherein said system is capable of producing an exhaust gas recirculation event during at least one of a positive power mode of operation and a non-positive power mode of operation.

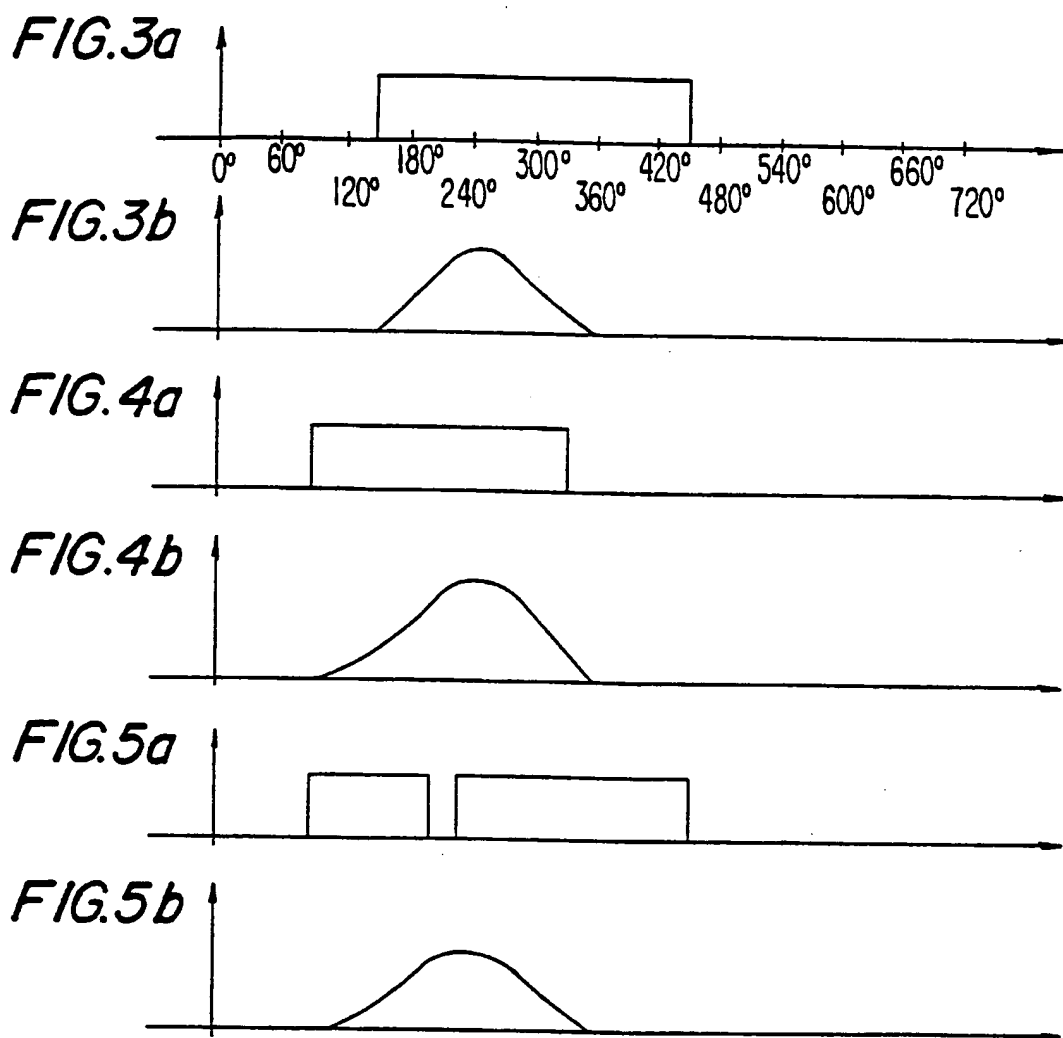




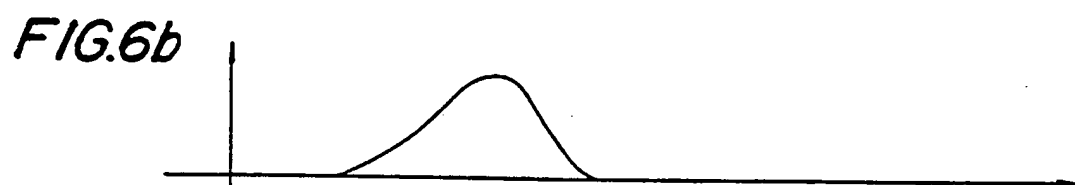
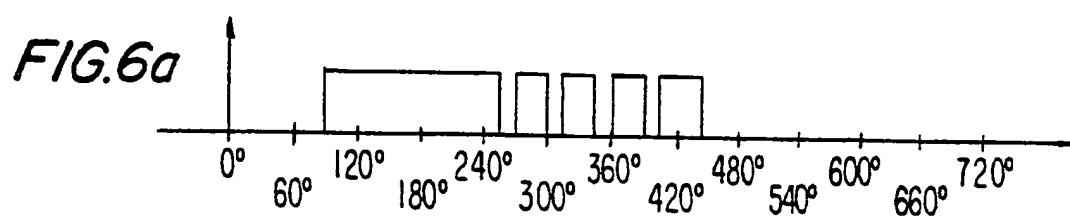
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3/8



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5/8

FIG. 7a

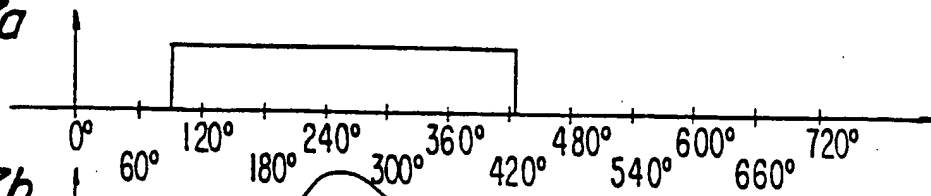


FIG. 7b

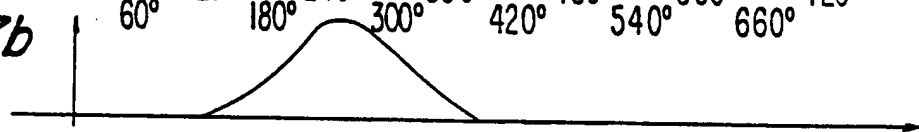


FIG. 7c

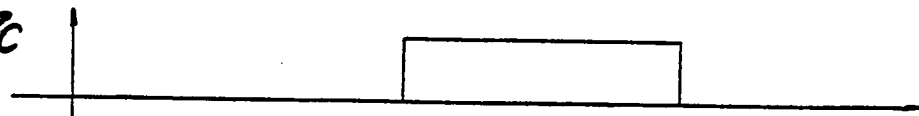


FIG. 7d



FIG. 7e



FIG. 7f



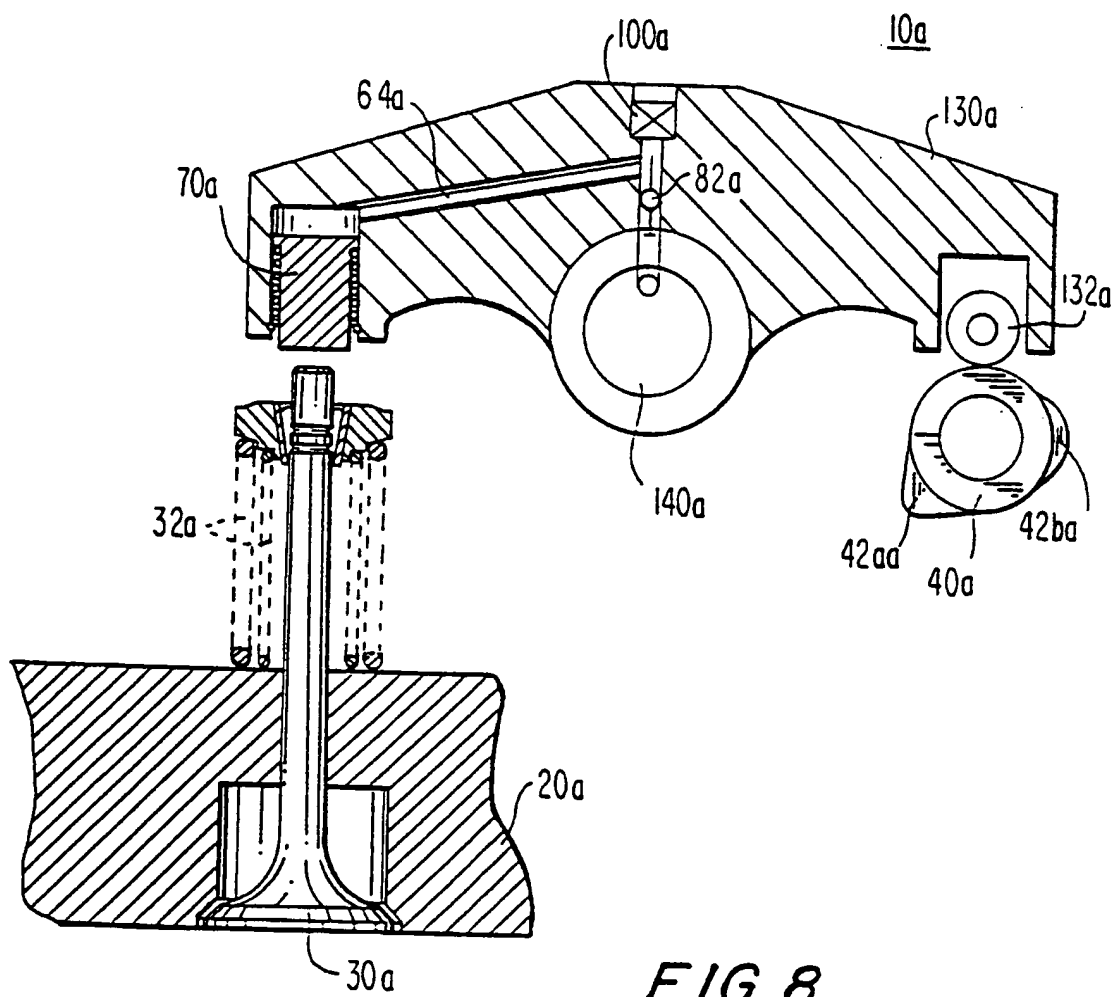
FIG. 7g



FIG. 7h



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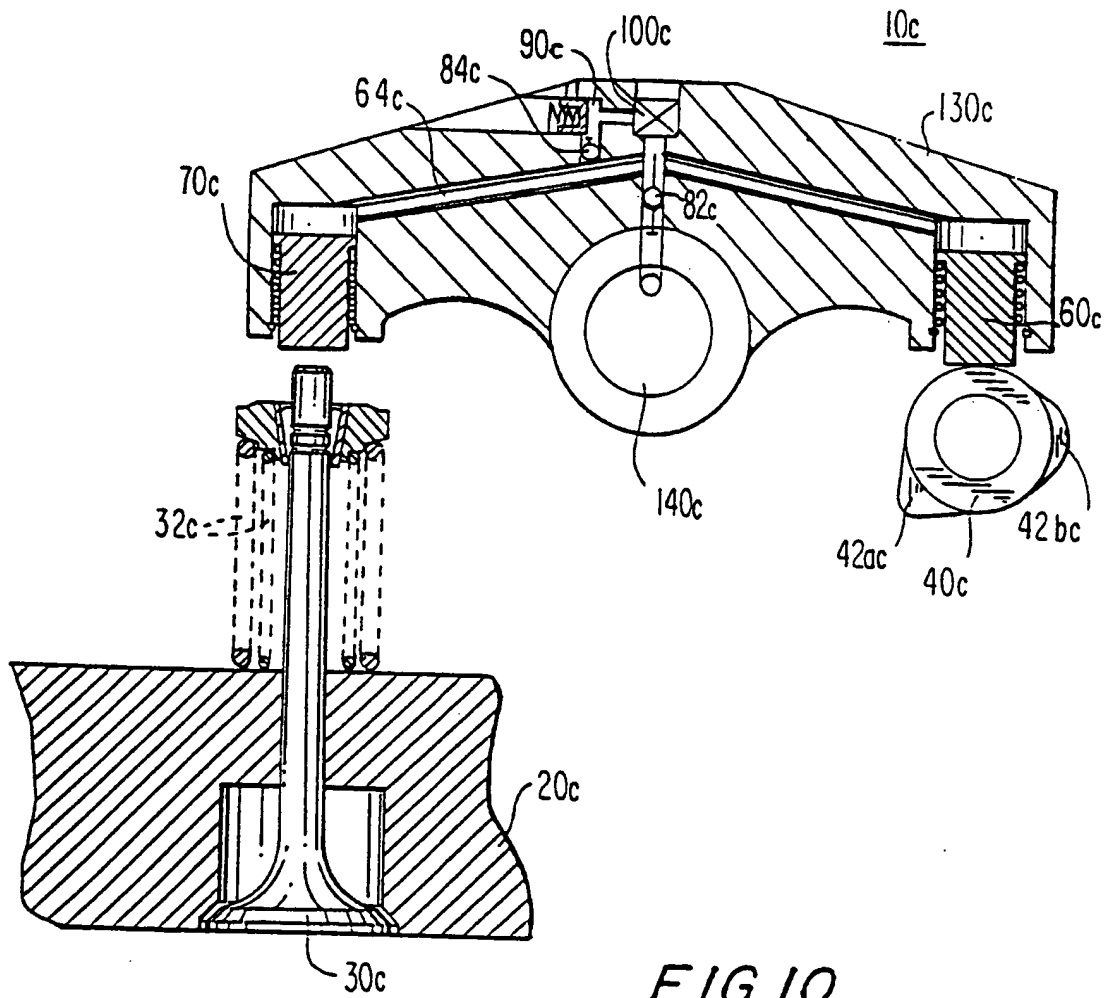


FIG. 10



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US99/27367

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> IPC(7) : F01L 13/06; F02M 25/06 US CL : 123/90.12, 90.6, 320, 321, 322, 323, 568.14 According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) U.S. : 123/90.12, 90.6, 320, 321, 322, 323, 568.14 Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 5,564,385 A (HAKANSSON) 15 October 1996, see entire document.	1, 2, and 4 --- 3
A	US 4,424,790 A (CURTIL) 10 January 1984, see entire document.	1-15
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* *A* *E* *L* *O* *P*	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier document published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	*T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art *A* document member of the same patent family
Date of the actual completion of the international search 08 MARCH 2000		Date of mailing of the international search report 05 APR 2000
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230		Authorized officer WEILUN LO <i>Diane Smart</i> Telephone No. (703) 308-1957